Novel Bonding Methodologies Toward the Attainment of Primary Bonded Aircraft Structure Project WBS Number: 694478.02.93.02.12.18.23

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Purpose

The focus of the work is to develop an environmentally friendly surface treatment for adhesive bonding of titanium alloys (Ti) using a Nd:YAG laser to create specific surface chemistry and topography. The novelty lies in the creation of precise patterns on the order of 5-10 microns deep into the surface of the Ti while simultaneously producing chemical changes to the surface in a manner analogous to that of the state-of-the-art (SOA) chemical etch surface treatments.

The objective of this work is to develop an environmentally friendly surface treatment for titanium alloys using a laser that provides reproducible, reliable and measurable performance consistency. The advantage it has over the state-of-the-art chemical dip process is that it is rapid, precise, reproducible and amenable to scale-up for production, and does not require the use of toxic chemicals. Thus progress of this project for FY 13 can be judged as indicated below.

Progress Assessment

Demonstrate that the laser ablation surface treatment process on Ti-6Al-4V alloy provides adhesion and mechanical properties comparable to those of the state-of- the-art while eliminating environmentally unfriendly chemical dip processes. This has been successfully demonstrated by the tests conducted and described herein. Two chemical surface treatment processes can be replaced (HF/HNO_3 and TiBoe), and the laser surface treatment process does not significantly affect the fatigue behavior of the Ti-6Al-4V alloy.

Background

Aircraft manufacturers rely increasingly on adhesive bonds to simplify airframe design and improve aircraft performance. Metal to composite bonds are becoming more common as the composite content of an aircraft is increased. Replacing mechanically fastened joints with adhesive bonds can reduce weight, simplify manufacturing, and provide a stronger, more reliable joint, but solely bonded joints are rarely implemented in the primary structures of commercial aircraft due to predictability concerns and the inability to non-destructively assess bond strength. Restrictions on the application of adhesively bonded joints stem from a lack of control in current bonding methods. New surface preparation methods, which promise to improve repeatability, minimize waste, and reduce costs, are becoming increasingly important to aircraft manufacturers. The premature or unexpected failure of an adhesive bond can usually be traced to defects in the preparation of the faying surface. Current surface treatment techniques based on mechanical abrasion such as grit blasting or sanding have limited repeatability and can leave contamination that reduces bond performance. SOA methods for modifying the surface chemistry of titanium alloys depend on wet chemical etchants containing acids, caustics, and oxidizers, usually in combination. Such processes are expensive to perform because they are dangerous, create large volumes of hazardous waste, and are difficult to automate. The automation of surface preparation, which increases reproducibility, may be necessary for the certification of bonded primary structures. As mentioned, the SOA surface preparation for Ti uses multi-step chemical-dip processes each of which is costly due to special handling and use requirements, facility maintenance, hazardous waste remediation, and quality control requirements. This surface treatment process for Ti is expensive to install, maintain, monitor and utilize in a production environment, and the chemicals involved are potentially hazardous to workers and the environment. There is presently a strong desire in the aircraft manufacturing industry to obtain Federal Aviation Administration (FAA) certification for adhesive bonding of primary aircraft structure. The industry and FAA believe that the path to certification of adhesive bonding for primary aircraft structure is strongly dependent on process control in manufacturing and shop environments. It is well known that controlled substrate surface treatment is fundamental for the initial and long-term performance of adhesively bonded joints. Non-standard techniques such as atmospheric pressure plasma, arc discharge, and laser irradiation have been demonstrated, but are still undergoing evaluation by the aerospace industry. An alternative approach, laser ablation, is a subtractive process which relies upon highly-focused laser radiation to remove and redistribute material on a surface. Ultra-violet laser systems are commonly used for high precision work such as medical procedures, the machining of fine parts, and printing microelectronic circuit patterns. The ablation process has been demonstrated to generate high precision surface topography simultaneously with the removal of surface contaminants and modification of surface chemistry. To advance adhesive bonding towards FAA certification, there is clearly a need for an automated, reliable, scalable, repeatable, high precision and robust surface treatment process for Ti (as well as other structural airframe materials). The work discussed here utilizes laser ablation patterning as a surface preparatory treatment for Ti-to-Ti adhesive bonding that satisfies all of these requirements.